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Investigation of the possibility of providing no-break electric power using a gas turbine as the emergency prime mover

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INVESTIGATION OF THE POSSIBILITY OF PROVIDING NO-BREAK ELECTRIC POWER USING A GAS TURBINE AS THE EMERGENCY PRIME MOVER

by

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PROVIDING NO-BREAK ELECTRIC POWER USING
A GAS TURBINE AS THE EMERGENCY
PRIME MOVER

by

James R. Borberg

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of the Department of Mechanical Engineering
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Approved:

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Advisor

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ABSTRACT

The specific problem in this investigation is to determine if a no-break electric power system using a gas turbine as the emergency prime mover can be manufactured and operated within certain specified limits to provide continuous electric power to the critical portions of Naval Communications equipment.

The present method of providing no-break electric power is to use a diesel engine as the emergency prime mover. These systems are considered to be too bulky, heavy, and expensive. The gas turbine system must be so designed as to overcome these disadvantages.

One system is proposed that can be manufactured from equipment now available; however, this system while being less bulky and weighing less than the diesel system, costs more to own and operate.

Another system is proposed that will satisfy the design requirements; however, it cannot be manufactured without certain basic changes in gas turbines that are now commercially available.

PART I

INTRODUCTION

A. Introduction

In order to maintain a highly reliable Naval Communications system under all conditions, it is imperative to provide an uninterruptible power supply to certain components of the system. Any variation in excess of the criteria requirements constitutes an interruption which will result in communications failure. If the interruptions are frequent, or persist for any length of time, because of the complexity of the communications system, extensive time will be consumed in rectifying the situation resulting from such failures. A limited degree of interruption may be tolerated during peacetime; however, during wartime criteria requirements must be met if an effective communications system is to be maintained.

The provision of uninterruptible electric power is of concern to the Navy and to the Bureau of Yards and Docks which is responsible for providing this utility. The no-break equipment, in many cases, will be used overseas where size, weight, complexity and maintenance is of prime importance. The no-break equipment should therefore:

1. Be composed of a minimum of different pieces of highly reliable and easy to maintain components.

2. Meet a basic minimum criteria of $\pm\frac{1}{2}$ CPS (about 1%) and $\pm$ 2% voltage variation under normal operating conditions with not more than $\pm$ 1.2 CPS (2%) and $\pm$ 2% voltage variation under all fault conditions with normal conditions restored within 30 seconds. Fault conditions consist of single-phase and three-phase open circuits,

single-phase and three-phase short circuits, and single-phase and three-phase grounds.

3. Operate at minimum cost considering both first cost and operating costs.

There is no system that has been developed to date that will provide completely uninterruptible electrical power, since there must be some form interruption that signals failure. The problem is to detect this failure and to supply an alternate source of power without loss of voltage or frequency below an acceptable minimum. All primary electrical feeds are subject to failure and these interruptions are normally unpredictable. There is no overall solution to the Navy's problem of an uninterruptible power system, using present commercial plants, which will satisfy all design requirements.

B. Historical Review

There have been four basic methods for providing "no-break" electric power developed by industry. Each of these systems provide several desirable features, but none of them contains all the characteristics required by the Navy.

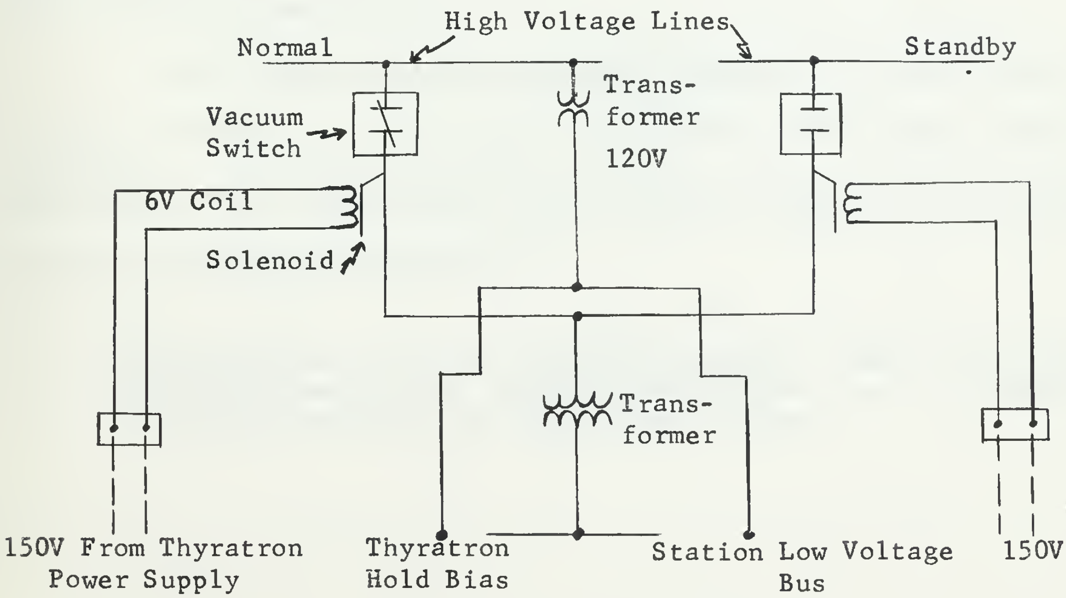

Figure I. High Voltage Switch

Perhaps the simplest method developed is to provide an electrical supply from one Utility line with a second independent Utility line as a stand by. This can be provided by a Jennings High Voltage Switch, enclosed within glass and pumped to a low pressure, used to switch primary voltage from the normal feeder to a standby feeder upon failure of the normal source. This switch as shown in Figure I is a high speed opening or closing device. When opening the circuit, the switch will positively break the current at the next current zero point after contacts are opened. Under this arrangement, the current will be interrupted sometime within an interval between two and eight milliseconds after contact separation.

The normally "open" and normally "closed" vacuum switch for each phase will be operated by solenoids. The contacts would be arranged so that when the solenoids are de-energized, the load would be connected to the normal line. The current would part the contacts of the three normally "closed" switches in two to four milliseconds and would close the contacts of the three normally "open" switches in less than 10 milliseconds. (This is within a special criteria requirement for short period total interruption).

The voltage during the transfer period would be low or non-existent, but for a period of less than 10 milliseconds which would be acceptable. The frequency before and after the transition period would be within acceptable tolerances.[1 *]

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*Throughout this thesis, superscript numbers refer to the similarly numbered items in Part IV, LITERATURE CITED, used in support of statements preceding the superscript numbers.

Even though the service record of Utility Companies may be good there are many conditions that exist which would not normally be called an interruption but would be an interruption as far as the critical loads are concerned. These conditions would be such things as variations during switching operations, terrestial storms, load variations and normal minor voltage fluctionations. Other important considerations that would prohibit the use of this system are:

1. The difficulty of obtaining two truly independent Utility lines. In many cases two separate feeds can be obtained, but a single failure at some point in the system may cause failure in both feeds. Usually different supplies from two different Utility Companies are not available.

2. Enemy attack or sabotage could easily destroy one or both of the supplies which normally come from long distances and in many cases through areas remote from population centers and not easily protected.

3. Usually at overseas bases or under emergency conditions, a second source of power would not be available.

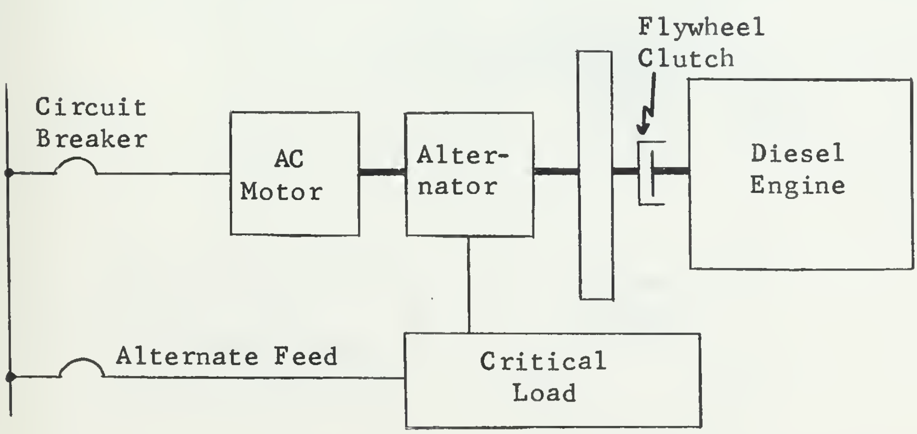

Figure II. Diesel No-break Power System

The second method, shown in Figure II, consists of an electric motor connected through a circuit breaker to the normal power supply and driving an alternator and an inertia flywheel. The alternator is always connected to the critical load. The inertia flywheel is connected in line with a clutch to the diesel engine. Upon normal power failure the inertia flywheel is connected by a clutch to the diesel engine which is cranked to operating speed. During this period the flywheel will drive the alternator and continue to supply power to the critical load until the diesel engine begins to supply the driving force (about 1 second). This system will meet the criteria requirements and can be recommended. It should be noted that while this system will meet the electrical criteria requirements it is heavy, bulky, and expensive.

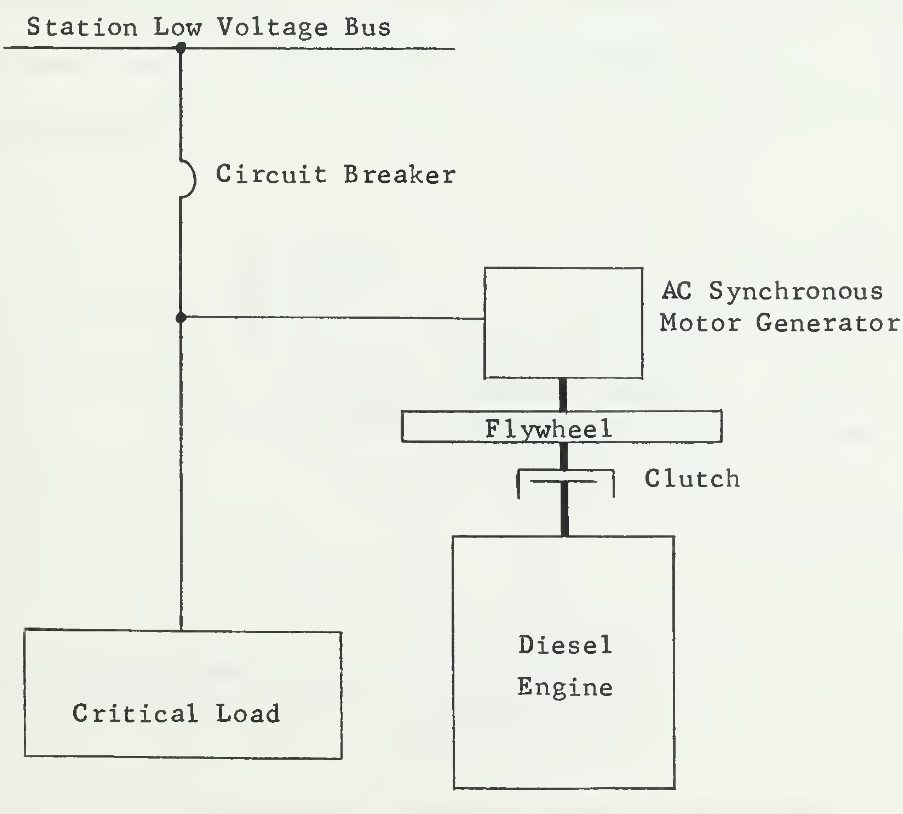

Figure III. Diesel No-break Power System

The third method, shown in Fugure III, is little more than a variation of the second method and consists of a synchronous motor-generator, which under normal conditions is connected through a circuit breaker to the normal power supply and running as a synchronous motor. The motor only draws sufficient energy to provide for friction losses. The critical load is connected to the terminals of the synchronous motor-generator and to the normal power supply. Upon failure of the power supply the synchronous motor-generator becomes a synchronous generator feeding the critical load. The diesel engine is then started as outlined in the second method. By the use of this third method the normal switch over would be within criteria limits except if a short circuit fault occured in the normal power source. In this case the generator would feed current into the short and in the interval required to disconnect the line load, the voltage and frequency would drop to unacceptable limits. This variation on the second method is, therefore, not satisfactory.

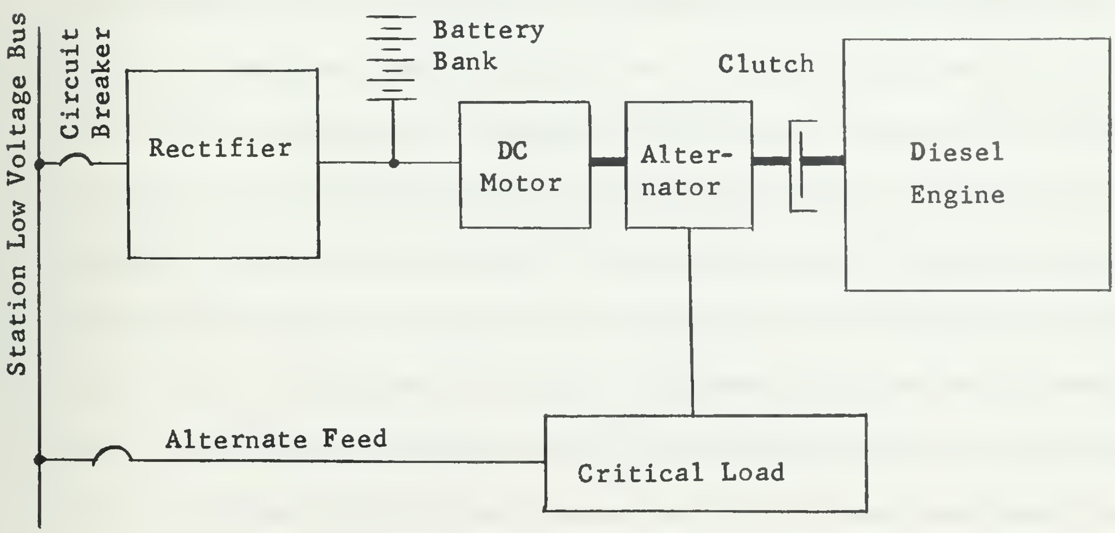

Figure IV. Diesel No-break Power System

The fourth method, shown in Figure IV, consists of a motor-alternator set that is normally connected to the regular power supply. The DC motor receives current through a rectifier and in turn drives the alternator which supplies power to the communications equipment. In case of normal power failure, batteries which are in parallel with the rectifier and motor, drive the alternator to provide continuous power to the critical load. During this period a standby diesel engine will automatically be started and connected to the alternator by means of a clutch. This method is regarded as very reliable and will meet the minimum interruption criteria; however, the batteries, rectifier, and DC motor make this system somewhat more complicated than the second system with little or no increase in performance. For these reasons, this system is not recommended.

C. Statement of the Problem

Present day Naval Communications equipment require a supply of uninterruptible power to the vital components of these communications installations. The fundamental requirements are established by the electronic equipment manufacturers from the operating characteristics of the vital components. At present the criteria requires that frequency can deteriorate approximately two cycles per second and the voltage can drop 10%. Therefore, under worst conditions, even during transition, the frequency cannot be less than 58 cycles and the voltage no less than 90% of normal. Equipment that will be operating in the near future will require continuous power that does not vary more than ½ cycle per second or 2% in voltage during normal operation. The present equipment used to provide "no-break" power is expensive to own and operate. It is also

larger and heavier than is desired to be readily transported to isolated locations under adverse conditions.

What is needed is equipment that is able to meet the new criteria, while being smaller, lighter in weight, lower in cost, simpler, rugged, and require less maintenance.

The proposed method of solving this problem is to provide a motor-alternator set with emergency power supplied by a gas turbine. This unit to provide uninterruptible electrical power at $\pm \frac{1}{2}$ CPS (about 1%) and $\pm$ 2% voltage variation during normal operation. Maximum variation during transition and emergency operation is $\pm$ 1.2 CPS and $\pm$ 2% voltage with normal conditions restored within 30 seconds. Utilization of a gas turbine would reduce the weight and size of the prime mover as well as providing a highly reliable source of power.

D. Method of Procedure

Specific information that must be obtained and areas to be investigated are as follows:

1. Size of components required to operate alternators of 40, 60, 100, 150, and 200 KW capacity.
2. Consideration of various systems and equipment.
3. Determination to what extent the power demand, which varies from 75% to 100% of full load, will have on the gas turbine.
4. Weight of the gas turbine systems versus diesel systems.
5. Cost of the gas turbine systems versus diesel systems.
6. Method of speed control and maximum voltage and frequency variation that will result.
7. Maintenance and installation cost comparison.

PART II

DISCUSSION

A. System A

1. General operation.

The first method investigated consists of a rectifier changing line voltage (208 Volt AC) to 240-250 Volt DC to power a DC motor. The DC motor in turn drives an alternator which supplies electricity to the critical load. A diagram of this system is shown in Figure V. In the event of power failure, a battery bank which replaces the rectified Utility power, will provide power for up to two minutes. A gas turbine is automatically started when the batteries begin supplying power and upon reaching full operating speed (about 20 to 25 seconds) is automatically connected through a clutch to the alternator.

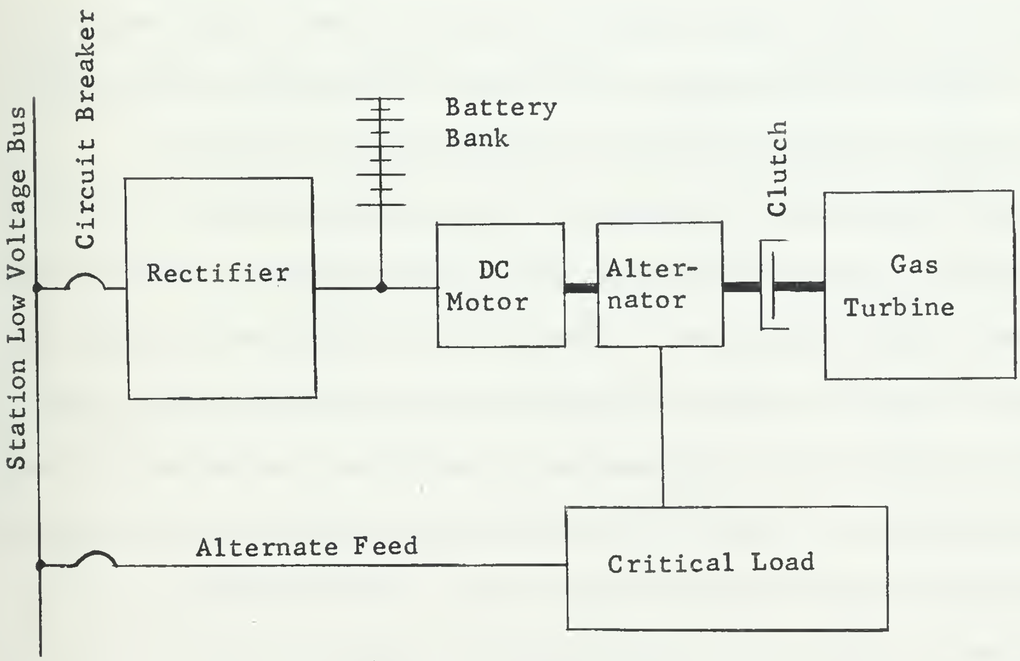

Figure V. System A

2. Detailed operation.

To illustrate the details of this arrangement, a 60 KW output Gas Turbine No-break Power System will be described in detail. All of the equipment required is standard and can be obtained from any of a number of manufacturers.

A 100 KW rectifier will receive the 208 volt 60 cycle AC line voltage and supply 240 volts DC to the DC motor. The rectifier is normally rated at 100% load continuously and 125% for two hours. The unit is air cooled by natural convection and there are no moving parts to maintain or lubricate. All components are accessible from the front for quick inspection. The only maintenance required is an occasional vacuuming of the internal assembly. The nonaging silicon cells provide an efficiency of 94%. Since the silicon diodes allow the current to pass in only one direction there is no possibility of the batteries or generator supplying power to the utility line in case of a short circuit or voltage drop. When the Utility voltage drops 5 volts or 2% (from 240V to 235V) the Utility circuit will automatically be opened.

A battery bank connected in parallel with the rectifier and at 245 volts will automatically be connected to the DC Motor when the Utility line is disconnected. (The variation in cycles in the AC line has little or no effect on this system). The battery bank is maintained 5 volts above the normal rectified power so that as current is supplied from the batteries, the change in voltage will not be enough to change the DC motor speed by more than ± 2% or 1.2 CPS. This speed variation will not be great enough to cause the alternator voltage to vary more than ± 2%. Since current can flow through the rectifier in one direction

only, the rectifier will prevent the batteries from feeding current to the Utility line during emergency operation. The batteries will have sufficient capacity to power the load for 2 minutes; however, 20 to 25 seconds will normally be sufficient to start the gas turbine. Batteries can be selected that are highly reliable, have a long life, and except for infrequent addition of water require no maintenance.

A standard DC motor-alternator set will normally be powered by Utility line voltage and will supply electric power to the critical load. In event of line power failure the batteries will supply emergency power to the DC motor until the gas turbine can be started.

When the circuit breaker in the Utility line opens, the gas turbine will automatically be started. After the gas turbine is started and is operating at full speed (about 20-25 seconds), a clutch is electrically engaged connecting the turbine to the alternator. With the gas turbine driving the alternator, no further power is required from the batteries and they are automatically disconnected. Information received on typical gas turbines such as AiResearch gas turbines indicates that they are a versitile source of constant speed shaft power. One class of turbines which will be described in detail, sized for 40KW and 60KW generators, are typical of all AiResearch turbines (and similar to other manufacturers equipment) which have demonstrated long service life between overhauls, low maintenance cost, and are capable of starting and operating reliably at temperatures ranging from -65°F to 130°F under world wide environmental and altitude conditions. This typical unit consists of a compressor section, a power turbine section with integral drive pod, and controls. The compressor is a two-stage centrifugal type

utilizing two radial outward flow impellers. Air enters the single entry first stage impeller through a compressor inlet plenum and flows through a vaned diffuser into the inlet of the single entry second stage. Air discharges from the second stage compressor through a vaned diffuser into the turbine plenum. The impellers mounted on a common shaft are coupled to the turbine rotating assembly and to the accessory assembly by means of quill shafts. The power turbine section consists of a turbine assembly, a plenum, a torus, and a combustor chamber assembly. The plenum serves as a receiver of the compressor discharge air and has an enclosure for the combustion tube and the torus. The torus, which mates with the discharge end of the combustor chamber flame tube, directs the hot combustion gases through a fixed-area nozzle ring against the radial inflow turbine wheel. The turbine wheel is mounted in a bearing carrier by two pressure lubricated ball bearings. The accessory section with integral drive pad and output shaft includes the following: a starter; an oil pump assembly including pressure pump and dual scavange pump, oil filter and by-pass valve, and relief valve; a fuel accessory assembly which includes fuel pump, fuel filter, relief and by-pass valve, and governor, and fuel shutoff solenoid; a centrifugal three-speed switch, and a cooling fan. The turbine speed is regulated by a governor in the fuel pump and control unit assembly consisting of a pair of spring-loaded flyweights directly modulating a valve which by-passes high-pressure fuel to the fuel pump inlet. Action of the fuel governing system depends upon a functional relationship between load and governed speed for adequate stability. An isochronous governor provides precise frequency control, minimum frequency excursion with fast recovery and adjustable

linear droop for paralleling with line current. The turbine is equipped with a fully automatic control system which properly sequences starter operation, fuel control, and ignition to provide a stable automatic starting cycle requiring only the engagement of a single starter switch. Additional automatic controls provide continuous operating adjustments to compensate for variations in shaft power requirements, and ambient conditions. The unit will start easily at any time, even immediately after the stop switch has been actuated, and while the turbine is decelerating. This unit will provide $\pm$ ¼% steady state frequency control from no load to full load with recovery to steady state within one second. A list of gas turbines between 60 and 400 HP which are designed to drive generators and are manufactured in the United States, is contained in Appendix A.

Controls for a Gas Turbine No-break Power System would be essentially the same as are currently used on diesel units. Figure VI shows a diagram of the main portion of a control system used by Consolidated Diesel Electric Corporation on a pair of 60 KW diesel units. If power fails or falls below criteria limits, sensing relays open the commercial line contactor. It should be noted that this system does not provide sensing relays for voltage above criteria limits. For complete protection this should be provided; however, high voltage would normally be of short duration and generally would not affect the quality of power to the critical load. When the line contactor is opened the clutch is energized and the diesel engine is started. The inertia flywheel carries the load until the diesel engine is operating at full speed and assumes the load. During the diesel operation the Utility

power is constantly monitored and when it has returned to normal, the speed of the diesel engine is automatically varied until the electric power is synchronized, and the system is returned to the normal Utility power. The diesel engine is then shut down and goes on standby condition. The switchgear also contains sensing equipment on certain critical components of the system; meters for measuring amps, volts, frequency, and power factor; as well as fuses, circuit breakers, and interlocks for the protection of the system.

3. Quality of electric power.

Under normal conditions, with the alternator supplying power to the critical load, the voltage and frequency will be controlled with standard equipment to provide a frequency control of $\pm$ ½ CPS and voltage control of $\pm$ 2%. The transient dip in voltage will be negligible (less than $\pm$ 2%) during the transition period and the frequency will not vary more than $\pm$ 1.2 CPS with normal power restored within 21 to 26 seconds.

4. Reliability.

The reliability of this system is considered to be satisfactory. For operation under normal conditions the reliability of all types of no-break systems depends upon the successful operation of the motor-alternator set and the associated control equipment. Diesel systems utilizing this equipment are presently in use and their reliability is satisfactory.

The rectifier is a dependable piece of equipment that has been used successfully in numerous applications for many years and its reliability is at least equivalent to the other components of the system.

Numerous different types of batteries can be used such as those

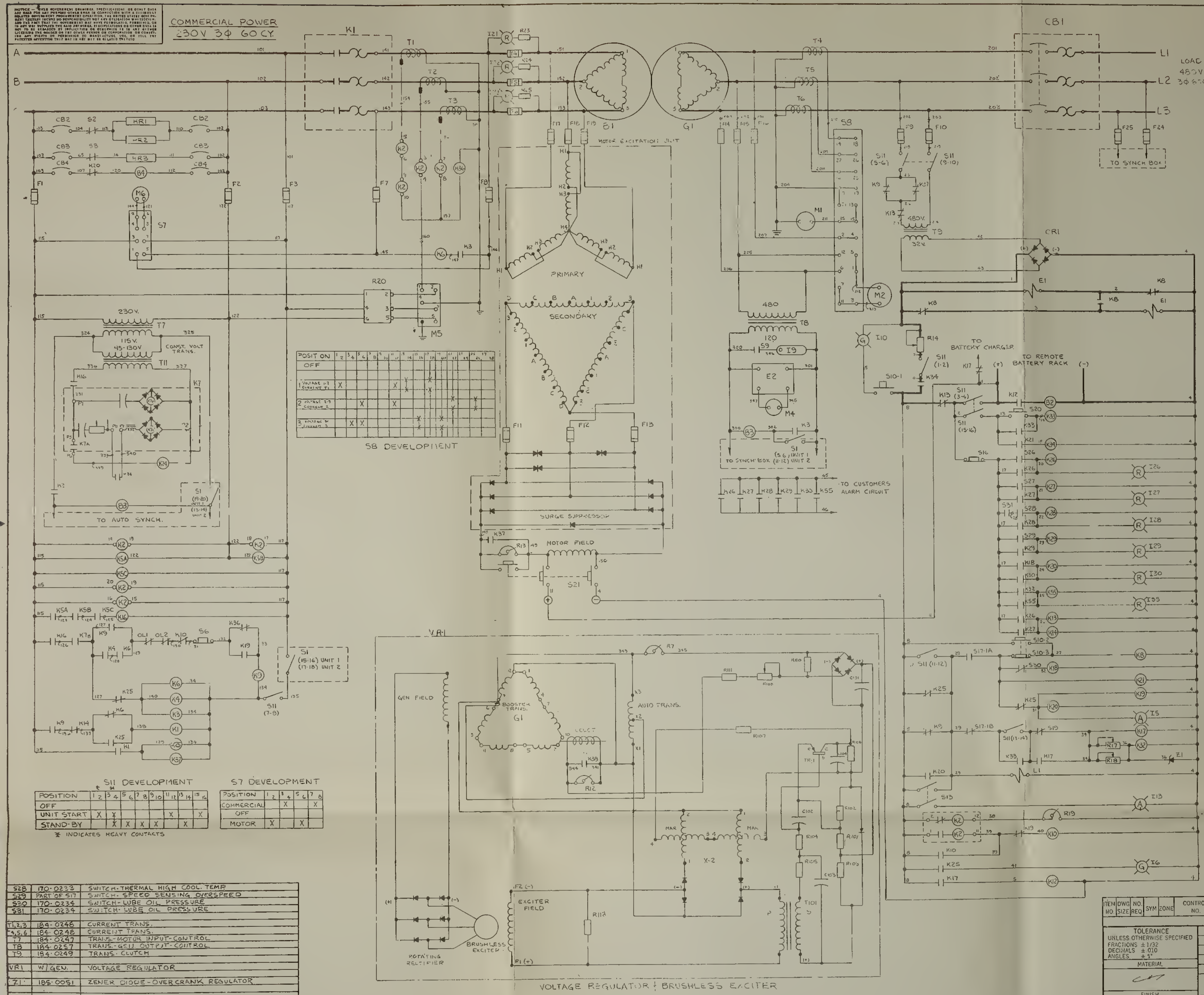

Figure VI

DO NOT SCALE DRAWING

REVISIONS

NOTICE	SYM	ZONE	DESCRIPTION	DATE	APPROVAL
16306	-	—	REL. FOR JOB 4191	1/18/63	ACA

15

DES	PART NO.	DESCRIPTION
B1	118-0112	MOTOR-MAIN DRIVE
B2	118-0035	MOTOR-STARTER
B3	4105-0054	MOTOR-ENGINE SYNCH. (DUAL)
B4	123-0139	MOTOR-LUBE OIL CIRCULATING PUMP
CB1	31-0259	CIRCUIT BREAKER-MAIN
CB2	31-0143	CIRCUIT BREAKER-COOLANT HEATER
CB3	31-0143	CIRCUIT BREAKER-LUB. OIL HEATER
CB4	31-0142	CIRCUIT BREAKER-OIL CIRC. PUMP
CR1	153-0076	RECTIFIER-CLUTCH
E1	253-0033	INDUCTION CLUTCH
E2	PART OF M4	TRANSDUCER FREQ. METER
F1,2,3	70-0055	FUSE-20A. 250V. COMMERCIAL A.C.
F4,5,6	70-0129	FUSE-250A.-250V. MOTOR MAINS
F7,8	70-0090	FUSE-5A-250V METER FROM MOTOR
F9,10	70-0095	FUSE-15A.-500V. CLUTCH & CONTROLS
F11,12,13	W/SYNCHRONEX	FUSE-MOTOR EXCIT. (SECONDARY)
F14,15,16	70-0095	FUSE-15A.-500V GEN. METERS & CONTROLS
F17,18,19	70-0055	FUSE-20A.-250V MOTOR EXCIT. (PRIMARY)
G1	76-0175	MAIN GENERATOR
HR1,2	277-0031	HEATERS-COOLANT
HR3	277-0030	HEATER-LUBE OIL
I5	0000-3252-17	INDICATING LIGHT-ENG DRIVE
I6	0000-3252-16	INDICATING LIGHT-UTILITY DRIVE
I9	106-0116	FLUORESCENT CABINET LIGHT
I10	0000-3252-31	INDICATING LIGHT-CLUTCH CONTINUITY
I13	W/S13	INDICATING LIGHT-ENG. TEST
I21,22,23	346-0056	INDICATING LIGHT-MAIN MOTOR FUSE
I26	0000-3252-02	INDICATING LIGHT-HIGH BEARING TEMP (FRONT)
I27	0000-3252-03	INDICATING LIGHT-HIGH BEARING TEMP (REAR)
I28	0000-3252-04	INDICATING LIGHT-HIGH COOLANT TEMP
I29	0000-3252-05	INDICATING LIGHT-OVERSPEED
I30	0000-3252-06	INDICATING LIGHT-LOW LUBE PRESSURE
I55	0000-3252-22	INDICATING LIGHT-ENG OVERCRANK
K1	172-0046	MAIN CONTACTOR
K2	154-0236	RELAY-REVERSE POWER
K3	154-0430	RELAY-ENGINE SYNCHRONIZER
K4	154-0336	RELAY-T.D.-DIESEL TO MOTOR
K5,A,B,C	154-0141	RELAY-POTENTIAL (UNDERVOLTAGE)-3
K6	4160-0022	RELAY ASS'Y-AUTO SYNCHRONIZER
K7	154-0502	RELAY-FREQ. SENSING
K8	154-0491	RELAY-CLUTCH CHANGE OVER
K9	154-0346	RELAY-TRANSFER MOTOR TO DIESEL
K10	154-0190-98	RELAY-REVERSE POWER SLAVE
K12	38-0053	CONTACTOR-MOTOR STARTER
K13	154-0489	RELAY-MASTER LOCKOUT
K14	154-0440	RELAY-MASTER LOCKOUT
K16	154-0345	RELAY-T.O. UNDERVOLTAGE
K17	154-0435	RELAY-STARTER PILOT
K18	154-0431	RELAY-T.D. LUBE OIL PRESSURE
K19	154-0392	RELAY-T.O. REVERSE POWER RESET
K20	154-0392	RELAY-T.D. ENGINE SHUTDOWN
K21	154-0483	RELAY-T.D. ENGINE START
K24	154-0501	RELAY-T.D. UNDERFREQUENCY
K25	154-0430	RELAY-MAIN CONTACTOR AUX. W/(2) 154-0436 AUX CONT.
K26	0000-3258	RELAY-BEARING TEMP. (FRONT)
K27	0000-3258	RELAY-BEARING TEMP. (REAR)
K28	154-0440	RELAY-HIGH COOLANT TEMP
K29	154-0440	RELAY-OVERSPEED
K30	154-0440	RELAY-LOW LUBE OIL PRESSURE
K32	154-0476	RELAY-T.D. ENGINE OVERCRANK
K33	154-0440	RELAY-UNIT START SLAVE
K34	154-0490	RELAY-CLUTCH SLAVE
K36	154-0056	RELAY-MOTOR UNBALANCED
K37	154-0488	RELAY-MAIN CONTACTOR SLAVE
K55	154-0440	RELAY-ENGINE OVERCRANK SLAVE
L1	W/ENG	SOLENOID-FUEL SHUT OFF
M1	117-1156	AMMETER A.C.-GENERATOR
M2	117-1157	VOLTMETER A.C.-GENERATOR
M4	117-1155	FREQUENCY METER
M5	117-1154	METER-POWER FACTOR
M6	117-1158	VOLTMETER A.C. COMMERCIAL
OL1	W/K1	OVERLOAD-MOTOR STARTER
OL2	W/K1	OVERLOAD-MOTOR STARTER
R7	W/GEN.	VOLTAGE ADJUSTING RHEOSTAT
R12	W/GEN.	RHEOSTAT-CROSS CURRENT COMPENSATION
R13	142-0243	RHEOSTAT-MOTOR FIELD
R14	155-0357	RESISTOR-CLUTCH
R17	155-0340	RESISTOR-BALLAST
R18	155-0340	RESISTOR-BALLAST
R19	142-0217	RHEOSTAT-REVERSE POWER SENSING
R20	W/M5	RESISTOR-P.F. METER
R23	155-0354	RESISTOR-MOTOR FUSE
R24	155-0354	RESISTOR-MOTOR FUSE
R25	155-0354	RESISTOR-MOTOR FUSE
S2	170-0170	SWITCH-COOLANT HEATERS
S3	170-0170	SWITCH-LUBE OIL HEATER
S6	0000-3252-18	SWITCH-LOAD TEST
S7	170-0715	SWITCH-VOLTMETER SELECTOR
S8	170-0575	SWITCH-AMM VOLTMETER SELECTOR
S9	170-0151	SWITCH-CABINET LIGHT
S10	0000-3252-31	SWITCH-CLUTCH MAINT.
S11	170-0724	SWITCH-MASTER SELECTOR
S13	0000-3252-32	SWITCH-ENGINE TEST
S16	0000-3252-20	SWITCH-FAULT RESET
S17	170-0599	SWITCH-CENTRIFUGAL
S19	170-0234	SWITCH-LUBE OIL PRESSURE
S20	0000-3252-33	SWITCH-UNIT START
S21	170-0604	SWITCH-VOLTAGE BUILD-UP
S26	170-0451	SWITCH-THERMAL BEARING (FRONT)
S27	170-0451	SWITCH-THERMAL BEARING (REAR)
S28	170-0233	SWITCH-THERMAL HIGH COOL. TEMP
S29	PART OF S17	SWITCH-SPEED SENSING OVERSPEED
S30	170-0234	SWITCH-LUBE OIL PRESSURE
S31	170-0234	SWITCH-LUBE OIL PRESSURE
T1,2,3	184-0246	CURRENT TRANS.
T4,5,6	184-0248	CURRENT TRANS.
T7	184-0247	TRANS.-MOTOR INPUT-CONTROL
T8	184-0257	TRANS.-GEN. OUTPUT-CONTROL
T9	184-0249	TRANS.-CLUTCH
VR1	W/GEN.	VOLTAGE REGULATOR
Z1	185-0051	ZENER DIODE-OVERCRANK REGULATOR

ITEM NO.	DWG SIZE	NO. REQ	SYM	ZONE	CONTROL NO.	PART OR IDENTIFYING NO.	CODE IDENT	NOMENCLATURE OR DESCRIPTION	MATERIAL OR NOTE	SPECIFICATION	UNIT WT.

LIST OF MATERIALS OR PARTS LIST

NEXT ASS'Y	USED ON	NEXT ASS'Y	FINAL ASS'Y
	4191	1	
APPLICATION		QTY. REQ'D.	

TOLERANCE UNLESS OTHERWISE SPECIFIED
FRACTIONS ± 1/32
DECIMALS ± .010
ANGLES ± 1°

MATERIAL
FINISH
SPEC.

PROJECT	4191	
DRAWN	ISZTWAN	1/18/63
CHECKED	KRT	1-21-63
APPROVED	ACA	1-21-63
APPROVED		1-23-63
APPROVED		DATE
APPROVED		DATE 1-23-63
CONTRACT		

CONSOLIDATED DIESEL ELECTRIC CORP.
STAMFORD, CONN.

SCHEMATIC DIAGRAM
60 K.W. 480 V. 60 CY.
3 W. M-G U.P.S.

CODE IDENT NO	SIZE	DWG NO.
93568	F	4191-0004
SCALE	WEIGHT	SHEET OF

designed primarily for marine or industrial use. The batteries are highly dependable and are designed for rugged use. A battery charger will automatically maintain the batteries at full charge and will recharge the batteries after each use.

In the last decade, the small gas turbine has emerged from development to a production status in a number of military and commercial applications. Experience in these applications which include many using the gas turbine as a prime mover for a generator set, has proved the turbine to be a reliable engine in actual field service. In a recent test of 100,000 hours of operation on each of two models in the AiResearch model 85 series, resulted in mean time between failure (MTBF) values of over 1,000 hours.[2] A more recent test has resulted in a different model reaching a MTBF of over 4,000 hours. This results in a reliability (R) of $R = e - \frac{t}{MTBF}$ where t = mission time (hours). With a mission time of up to 10 hours (assuming MTBF = 1,000 hours), the reliability of 99%. The MTBF naturally varies for each model gas turbine--this illustration, however, indicates the range that can be expected. Recently a Boeing Gas Turbine completed a 5,000 start test in an Air Force evaluation. Reliability comparisons particularly favor the gas turbine in the area of starting reliability, due to its simplicity, lack of rubbing surfaces, and consequent relative ease of starting.

5. Maintenance.

The maintenance of this System would be substantially the same as for a diesel unit with the exception of the gas turbine and batteries. The batteries require only the occasional addition of

of water (normally one or two times a year) and charging after use. A small gas turbine requires only the following maintenance:[2]

1. Pre-start inspection (normal time required: 15 minutes), frequency-daily.

a. Visually inspect wiring, ducts, fittings, and tubings for leaks, chafing, and security of fastenings.

b. Inspect air inlet and exhaust ducts for freedom from obstruction.

c. Check oil level and replenish if required.

d. Check adequacy of fuel supply.

2. Periodic Inspection (normal time required: 1 hour), frequency-each 100 hours or 500 starts.

a. Inspect combustor assembly (remove, inspect, and replace).

b. Replace fuel and oil filter elements.

c. Change or clean and replace the turbine plenum check valve.

d. Change oil.

e. Inspect turbine wheel and exducer.

f. Clean compressor inlet screen.

3. Overhaul: typically every 1000 hours, but varies with the engine.

Training an operator, without previous experience, to the point where he can operate a gas turbine engine and perform routine maintenance usually requires 8 hours or less and is usually done in the field. Experience has shown that personnel who can be trained to operate gasoline or diesel engines can also be trained to operate gas

turbines without difficulty. Typical programs to train personnel for operation, maintenance short of complete overhaul, and trouble shooting of complete gas turbine-generator sets are usually of 2 weeks duration.

B. System B

1. General operation.

This system consists of an AC motor normally operating from Utility power driving an alternator and a DC motor as shown in Figure VII. The alternator is connected to the critical load and in event of normal power failure the battery bank will begin to power the DC motor which will drive the alternator in a manner similar to that described in System A.

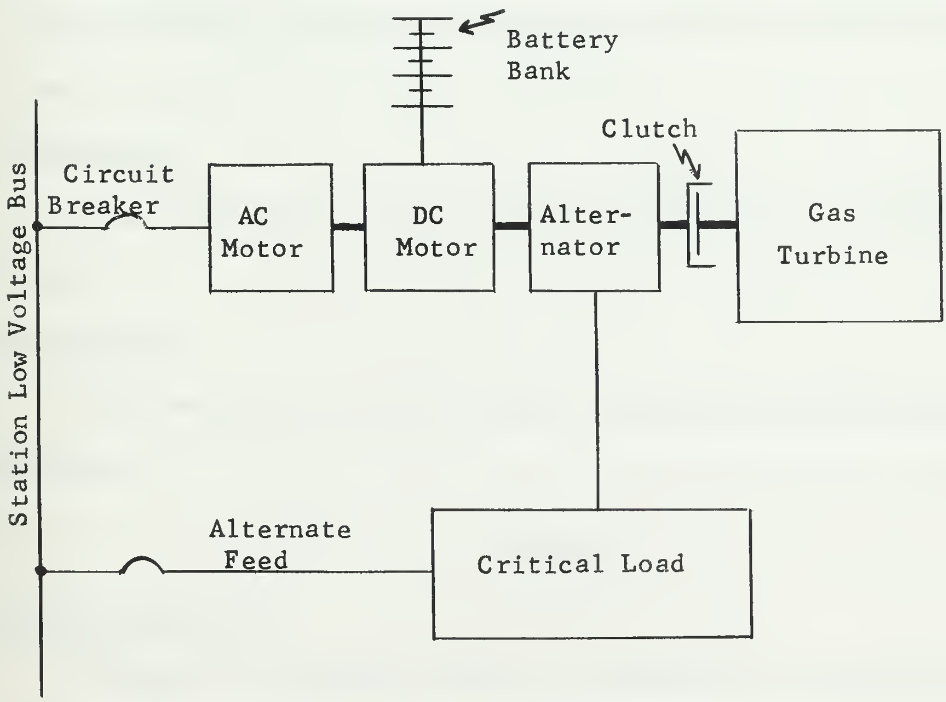

Figure VII. System B

2. Detailed operation.

This system will operate exactly as System A except that under normal operating conditions the Utility power will drive an AC motor instead of rectified power driving the DC motor. This system, therefore, does not require a rectifier but requires an AC motor in its place.

3. Quality of electric power.

With this system the Utility line voltage can vary ± 5-10% (depending on the motor used) before the gas turbine is started; however, a variation in frequency of ± ½ CPS will constitute an interruption. During normal operation and with the gas turbine furnishing emergency power the electric power to the critical load will be within ± ½ CPS and 2% voltage. During transition the voltage will not vary more than ± 2% and the frequency will not vary more than ± 1.2 CPS with normal conditions restored within 21 to 26 seconds from the time of failure.

4. Reliability.

The reliability of this system is essentially the same as for System A.

5. Maintenance.

The maintenance of this system is essentially the same as for System A.

C. System C

1. General operation.

Perhaps the simplest method of approach for providing no-break power with a gas turbine is to couple an evacuated gas turbine to the

shaft of the alternator and have an AC motor driving the alternator as shown in Figure VIII. The gas turbine would then be turning at full RPM and when started could accept load almost immediately. The size of the inertia flywheel would depend upon how fast the gas turbine could assume the load and where the flywheel was placed in the system.

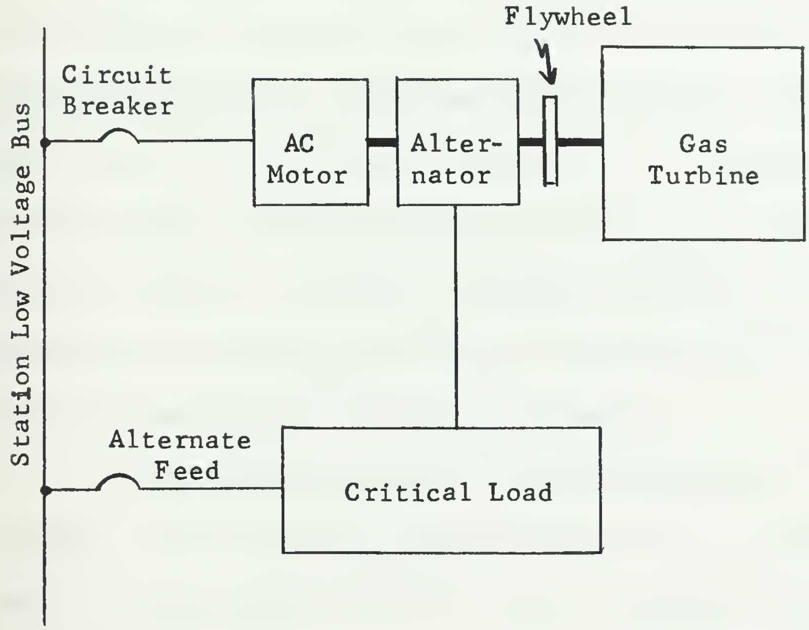

Figure VIII. System C

Information received from gas turbine manufacturers indicates that little or no experience is available for gas turbines being turned at full speed by an outside source of power; however, the general opinion is that present equipment cannot be operated in this manner. Some turbines would have difficulty in lighting due to the high velocity of fuel and air through the turbine at full RPM.

Solar and AiResearch advised that driving a turbine at synchronous speed in a vacuum presents a serious problem of lubrication. They considered the possibility of mist lubrication; however, it would not function properly in a vacuum. None of the turbines investigated could be operated in this manner.

2. Detailed operation.

If gas turbines can be developed so that they can be driven at full RPM by an outside power source this system would prove to be highly desirable. For normal operation of such a system the Utility power would drive an AC motor connected to an alternator, flywheel, and gas turbine. In the event of a power failure (Utility voltage variance of from $\pm$ 5 to 10% or frequency variance of $\pm$ 1%) the flywheel would drive the system until the gas turbine could be started. Control of this system would be similar to System A.

As an example, to show the possibilities of this system, consider a 100 KW No-break System consisting of a gas turbine with moment of inertia (I) = 0.028 lb-ft-sec^2 normally turning at 38,000 RPM and the AC motor, alternator, clutch, etc., with I = 3.13 lb-ft-sec^2 turning at 3600 RPM. If the speed is allowed to decrease 1% or 0.6 CPS before the normal power supply is disconnected and the gas turbine start sequence is initiated, and the speed is allowed to decrease another 1% or 0.6 CPS in 2 sec while the gas turbine is started; the size of the flywheel required would be calculated as follows:

Turbine Energy

$$E_1 = 1/2\ IW^2 = \left[\frac{.028}{2}\ \text{lb-ft-sec}^2\right]\left[\left(\frac{37,620\ \text{Rev}}{\text{min}}\right)\left(\frac{\text{min}}{60\ \text{sec}}\right)\left(\frac{2\pi\ \text{rad}}{\text{rev}}\right)\right]^2$$

$$= 218,000\ \text{ft-lb}$$

$$E_2 = 1/2\ IW^2 = \left[\frac{.028}{2}\right]\left[\frac{(37,240)\ (2\pi)}{60}\right]^2$$

$$= 214,000\ \text{ft-lb}$$

$$E_1 - E_2 = 4,000\ \text{ft-lb}$$

$$\text{Flywheel effect from turbine} = \frac{4,000\ (\text{ft-lb})\ (\text{sec H.P.})}{500\ (\text{ft-lb})\ (2\ \text{sec})} = 3.64\ \text{H.P.}$$

AC Motor and Alternator Energy

$$E_1 = 1/2\ IW^2 = \left[\frac{3.13}{2}\right]\left[\frac{(3564)\ (2\pi)}{60}\right]^2$$

$$= 219,000\ \text{ft-lb}$$

$$E_2 = 1/2\ IW^2 = \left[\frac{3.13}{2}\right]\left[\frac{(3528)\ (2\pi)}{60}\right]^2$$

$$= 214,000\ \text{ft-lb}$$

$$E_1 - E_2 = 5,000\ \text{ft-lb}$$

$$\text{Flywheel effect from Motor-Alt.} = \frac{5,000}{(550)(2)} = 4.5\ \text{H.P.}$$

Total Turbine, Motor, and Alternator Flywheel Effect

$$= 3.64 + 4.5 = 8.14\ \text{H.P.}$$

or say 8 H.P.

Flywheel Size

$$\frac{IW_1^2}{2} - \frac{IW_2^2}{2} = (150 - 8\ \text{H.P.})\left(\frac{550\ \text{ft-lb}}{\text{HP sec}}\right)(2\ \text{sec})$$

$$\frac{I}{2}\left[\left(\frac{3564\ \text{rev}}{\text{min}}\right)\left(\frac{\text{min}}{60\ \text{sec}}\right)\left(\frac{2\pi\ \text{rad}}{\text{rev}}\right)\right]^2 - \frac{I}{2}\left[\frac{(3528)(2\pi)}{60}\right]^2 = (142)\ (556)\ (2)$$

$$I = 104\ \text{ft-lb-sec}^2$$

$$I = \tfrac{1}{2}\,\frac{W}{g}\,r^2 \qquad \text{Let } r = 2\ \text{ft.}$$

or

$$W = \frac{2Ig}{r^2} = \frac{(2)\ (104\ \text{ft-lb-sec}^2)}{(2\ \text{ft})^2}\ \frac{(32.2\ \text{ft})}{\text{sec}^2}$$

$$W = 1675\ \text{lb}$$

$$\text{Flywheel Thickness} = \frac{1675}{\pi\rho\, r^2} = \frac{1675}{\pi(4)\ (490)}$$

$$= .272\ \text{ft or } 3.28\ \text{in.}$$

This 1675 lb flywheel compares with an 8,000 lb flywheel normally used on a 100 KW diesel system. If the flywheel were turned at 8,000 RPM, the approximate output speed of many turbines, the flywheel weight would be:

$$\frac{IW_1^2}{2} - \frac{IW_2^2}{2} = (150-8)\ (550)\ (2)$$

$$\frac{I}{2}\left[\frac{(7920)\ (2\pi)}{60}\right]^2 - \frac{I}{2}\left[\frac{(7840)\ (2\pi)}{60}\right]^2 = 156{,}200$$

$$I = 22.3\ \text{ft - lb - sec}^2$$

$$W = \frac{2Ig}{r^2} \qquad \text{Let } r = 1.5\ \text{ft.}$$

$$= 640\ \#$$

If the flywheel were turned at 40,000 RPM, the approximate speed of many turbines, the flywheel weight would be reduced to:

$$\frac{I}{2}\left[\frac{(39{,}600)\ (2\pi)}{60}\right]^2 - \frac{I}{2}\left[\frac{(39{,}200)\ (2\pi)}{60}\right]^2 = 156{,}200$$

$$I = .92\ \text{ft-lb-sec}^2 \qquad \text{Let } r = .75\ \text{ft.}$$

$$W = \frac{(2)\ (.92)\ (32.2)}{(.75)^2}$$

$$= 105\ \text{lb}$$

It is easily seen that a large amount of flywheel size and weight reduction can be accomplished if adequate consideration is given to driving the flywheel at high speeds or even making it a part of the gas turbine.

Since the turbine described in the preceeding discussion is a turbine that is desired rather than one that is currently available, the following assumptions have been made:

1. The reduction gears are so designed that when power is applied to the output shaft, the turbine can be turned at full RPM.

2. The turbine runs in a partial vacuum (the inlet is closed).

3. The power requirement for driving the turbine (by external power)is about 2 times the drag loss for a disk of the same size and turning at the same speed (about 5 H.P.).

4. The additional air drag that results in the first portion of the start up period when the inlet is opened, is offset by output from the turbine during the final portion of the start up period.

Compared to Systems A and B, this System is very simple and does not require a rectifier, DC motor, batteries, or battery charger. This greatly reduces the cost of owning the system and reduces the possibility of failure. The size and weight is also greatly reduced thus making this system highly desirable.

3. Quality of electric power.

The regulation of power would be the same as for System B except that during transition the frequency would not vary more than + 0.6 CPS or - 1.2 CPS with normal power restored in about 3 seconds.

4. Reliability.

This System would be more reliable than either Systems A or B since there are fewer components to cause failure.

5. Maintenance.

The maintenance of this system would, in general, be less than for Systems A and B since it has fewer components.

D. System D

The question that next arises is, if the gas turbine cannot be operated at full speed externally powered, can it be operated at no load under its own power?

A typical gas turbine sized for a 60 KW generator is AiResearch Manufacturing Company of Arizona, turbine model GTP70-52. This turbine consumes about 50 lbs of fuel per hour at no load and an inlet temperature of 60^{o}F. Fuel consumption at this rate would be about 185 gallons per day or considering a cost of 10¢ per gallon, would cost about $18.50 per day. Fuel consumption at this rate would obviously be far too expensive and would make the cost of operation prohibitive. Also continuous operation would require a major overhaul approximately every 42 days (about 1,000 hours depending on the turbine). This overhaul period might be extended since operating temperatures would be reduced: however, continuous operation may cause other problems such as carbon buildup. Answers to these specific problems could only be found by operating numerous gas turbines at no load for extended periods of time.

Typical gas turbines of the sizes that could be used, such as manufactured by Solar Aircraft Corporation would require from 2 sec for the small sizes to 5 sec for the larger sizes to accelerate from

one-half to full speed. As a typical example a turbine sized for a 100 KW alternator would require 5 sec to accelerate to full speed. The size of flywheel required (assuming no friction) would be:

Flywheel size (neglecting flywheel effect from the motor-alternator set which is about 3.5% at 3600 RPM, of the total flywheel effect required).

$$\frac{IW_1^2}{2} - \frac{IW_2^2}{2} = (\text{H.P.})\ \left(550\ \frac{\text{ft-lb}}{\text{sec}}\right)\ (\text{T sec})$$

$$\frac{I}{2}\left[\frac{(1782)(2\pi)}{60}\right]^2 - \left[\frac{(1764)(2\pi)}{60}\right]^2 = (150)\ (550)\ (5)$$

$$I = 1030\ \text{ft-lb-sec}^2$$

$$W = \frac{2Ig}{r^2} \qquad \text{Let } r = 2.33\text{ft}$$

$$W = \frac{(2)\ (1030)(32.2)}{(2.33)^2} = 12{,}200\ \text{lb.}$$

Similar sized diesel units have a flywheel weighing 8400 lb; therefore, it can be seen that no real advantage is gained by this method, in fact, the fuel and overhaul costs alone, in conjunction with the related operating problems involved would make this system unsatisfactory.

E. Comparison of Basic System Size, Weight, and Cost

A tabulation of the size, cost, and weight for the main components of Systems A, B, and C along with a typical Diesel System (as described on page 4) are listed in Tables 1, 2, 3, and 4. Materials for Systems A and B are standard components that have been selected as an example of what can be manufactured from "off the shelf" equipment. The controls and minor components of these systems would be similar to

Table 1. Size, Weight, and Cost of a Typical Diesel System

COMPONENT	UNIT KW	OUTPUT	SPEED (RPM)	L (in)	W (in)	H (in)	WT (lb)	COST
	40KW							
Flywheel		- -	1800	- -	8	48	4,100	$ 2,600
A.C. Motor		75 HP	1800	34	20	21	795	1,711
Alternator		40 KW	1800	40	18	19	915	2,200
Diesel		67 HP	1800	62	32	50	2,045	2,200
Switchgear, Profit, etc.		- -	- -	27	35	74	3,145	27,539
TOTAL *				16 ft	5 ft	5 ft	11,000	$ 36,250
	60KW							
Flywheel		- -	1800	- -	10	56	6,970	$ 3,600
A.C. Motor		100 HP	1800	38	22	23	1,042	2,190
Alternator		60 KW	1800	44	20	21	1,145	2,700
Diesel		93 HP	1800	67	32	50	2,360	2,500
Switchgear, Profit, etc.		- -	- -	27	35	74	6,483	32,710
TOTAL *				16 ft	6 ft	5 ft	18,000	$ 43,700
	100KW							
Flywheel		- -	1800	- -	12	56	8,400	$ 4,200
A.C. Motor		175 HP	1800	51	23	24	1,305	4,000
Alternator		100 KW	1800	49	22	23	1,480	3,500
Diesel		162 HP	1800	71	39	57	2,700	3,500
Switchgear, Profit, etc.		- -	- -	27	35	74	9,115	47,300
TOTAL *				18 ft	6 ft	7 ft	23,000	$ 62,500

* Total lengths, widths, and heights does not include switchgear.

Table 1. Size, Weight, and Cost of a Typical Diesel System (Cont'd)

COMPONENT	UNIT KW	OUTPUT	SPEED (RPM)	L (in)	W (in)	H (in)	WT (lb)	COST
	150KW							
Flywheel		- -	1800	- -	16	56	11,180	$ 5,090
A.C. Motor		250 HP	1800	50	23	25	1,510	4,300
Alternator		150 KW	1800	51	22	23	1,675	4,750
Diesel		230 HP	1800	78	39	60	3,600	5,100
Switchgear, Profit, etc.		- -	- -	27	35	74	11,035	48,460
TOTAL *				19 ft	6 ft	7 ft	29,000	$ 67,700
	200KW							
Flywheel		- -	1800	- -	24	56	16,800	$ 6,700
A.C. Motor		325 HP	1800	63	29	26	3,150	5,900
Alternator		200 KW	1800	64	27	25	3,400	6,300
Diesel		324 HP	1800	95	48	64	4,700	8,500
Switchgear, Profit, etc.		- -	- -	-	-	-	12,950	53,850
TOTAL *				23 ft	6 ft	7 ft	41,000	$ 81,250

* Total lengths, widths, and heights does not include switchgear.

Table 2. Size, Weight, and Cost of System A

COMPONENT	UNIT KW	OUTPUT	SPEED (RPM)	L (in)	W (in)	H (in)	WT (lb)	COST
	40KW							
Batteries		245 V	- -	68	54	50	4,200	$ 2,800
DC Motor		60 HP	1800	39	20	24	955	2,500
Alternator		40 HP	1800	40	18	19	915	2,200
Rectifier		50 KW	- -	24	48	82	1,200	3,410
Gas Turbine		120 HP	1800	40	31	31	250	19,000
Battery Charger		- -	- -	15	26	26	150	1,500
Switchgear, Profit, etc.		- -	- -	27	35	74	2,500	27,500
TOTAL				10 ft	3 ft	4 ft	10,170	$ 58,910
	60KW							
Batteries		245 V	- -	68	54	50	4,200	$ 2,800
DC Motor		100 HP	1800	43	22	26	1,320	3,700
Alternator		60 KW	1800	44	20	21	1,145	2,700
Rectifier		100 KW	- -	48	51	76	2,700	5,800
Gas Turbine		158 HP	1800	40	31	31	250	19,000
Battery Charger		- -	- -	15	26	26	150	1,500
Switchgear, Profit, etc.		- -	- -	27	35	74	3,800	32,700
TOTAL				11 ft	3 ft	4 ft	12,565	$ 68,200
	100KW							
Batteries		245 V	- -	83	40	60	9,150	$ 5,800
DC Motor		150 HP	1800	48	25	29	1,895	5,000
Alternator		100 KW	1800	49	22	23	1,480	3,500
Rectifier		125 KW	- -	48	51	76	3,200	8,775
Gas Turbine		315 HP	1800	60	40	34	675	18,000
Battery Charger		- -	- -	17	30	30	200	1,700
Switchgear, Profit, etc.		- -	- -	27	35	74	4,200	47,300
TOTAL				13 ft	4 ft	4 ft	20,800	$ 90,075

Table 2. Size, Weight, and Cost of System A (CONT'D)

COMPONENT	UNIT KW	OUTPUT	SPEED (RPM)	L (in)	W (in)	H (in)	WT (lb)	COST
	150 KW							
Batteries		255 V	- -	80	58	60	11,000	$ 6,800
DC Motor		250 HP	1200	62	34	34	4,595	10,700
Alternator		150 KW	1200	54	24	24	1,875	5,516
Rectifier		200 KW	- -	59	70	90	5,200	12,940
Gas Turbine		315 HP	1200	65	40	34	675	18,000
Battery Charger		- -	- -	24	30	30	250	1,900
Switchgear, Profit, etc.		- -	- -	27	35	74	5,000	48,500
TOTAL				15 ft	4 ft	4 ft	28,595	$104,356
	200 KW							
Batteries		255 V	- -	80	58	60	11,000	$ 6,800
DC Motor		300 HP	1200	67	40	40	6,230	11,600
Alternator		200 KW	1200	64	27	25	3,600	6,900
Rectifier		250 KW	- -	59	70	90	6,200	16,150
Gas Turbine		315 HP	1200	65	40	34	675	18,000
Battery Charger		- -	- -	24	30	30	250	1,900
Switchgear, Profit, etc.		- -	- -	27	35	74	6,300	53,800
TOTAL				17 ft	4 ft	4 ft	34,255	$115,150

Table 3. Size, Weight, and Cost of System B

COMPONENT	UNIT KW	OUTPUT	SPEED (RPM)	L (in)	W (in)	H (in)	WT (lb)	COST
	40KW							
Batteries		245 V	- -	68	54	50	4,200	$ 2,800
DC Motor		60 HP	1800	39	20	24	955	2,500
Alternator		40 KW	1800	40	18	19	915	2,200
AC Motor		60 HP	1800	33	20	21	720	1,419
Gas Turbine		120 HP	1800	40	31	31	250	19,000
Battery Charger		- -	- -	15	26	26	150	1,500
Switchgear, Profit, etc.		- -	- -	27	35	74	2,500	27,500
TOTAL *				13 ft	3 ft	4 ft	9,690	$ 56,900
	60KW							
Batteries		245 V	- -	68	54	50	4,200	$ 2,800
DC Motor		100 HP	1800	43	22	26	1,320	3,700
Alternator		60 KW	1800	44	20	21	1,145	2,700
AC Motor		100 HP	1800	38	22	23	1,045	2,190
Gas Turbine		158 HP	1800	40	31	31	250	19,000
Battery Charger		- -	- -	15	26	26	150	1,500
Switchgear, Profit, etc.		- -	- -	27	35	74	4,000	32,700
TOTAL *				14 ft	3 ft	4 ft	11,110	$ 64,590
	100 KW							
Batteries		245 V	- -	83	40	60	9,150	$ 5,800
DC Motor		150 HP	1800	48	25	29	1,895	5,000
Alternator		100 KW	1800	49	22	23	1,480	3,500
AC Motor		150 HP	1800	41	23	25	1,400	3,320
Gas Turbine		315 HP	1800	60	40	34	675	18,000
Battery Charger		- -	- -	17	30	30	200	1,700
Switchgear, Profit, etc.		- -	- -	27	35	74	4,400	47,300
TOTAL *				17 ft	4 ft	4 ft	19,200	$ 84,620

* Total lengths, widths, and heights does not include Batteries, Battery Charger, or Switchgear.

Table 3. Size, Weight, and Cost of System B (Cont'd)

COMPONENT	UNIT KW	OUTPUT	SPEED (RPM)	L (in)	W (in)	H (in)	WT (lb)	COST
	150 KW							
Batteries		255 V	- -	80	58	60	11,000	$ 6,800
DC Motor		250 HP	1200	62	34	34	4,595	10,700
Alternator		150 KW	1200	54	24	24	1,875	5,540
AC Motor		225 HP	1200	48	23	25	1,700	4,900
Gas Turbine		315 HP	1200	64	40	34	675	18,000
Battery Charger		- -	- -	24	30	30	250	1,900
Switchgear, Profit, etc.		- -	- -	27	35	74	5,200	48,500
TOTAL *				19 ft	4 ft	4 ft	25,295	$ 96,320
	200 KW							
Batteries		255 V	- -	80	58	60	11,000	$ 6,800
DC Motor		300 HP	1200	67	40	40	6,230	11,600
Alternator		200 KW	1200	64	27	25	3,600	6,900
AC Motor		300 HP	1200	62	26	27	3,450	6,250
Gas Turbine		315 HP	1200	64	40	34	675	18,000
Battery Charger		- -	- -	24	30	30	250	1,900
Switchgear, Profit, etc.		- -	- -	27	35	74	6,500	53,800
TOTAL *				22 ft	4 ft	4 ft	31,705	$105,250

* Total lengths, widths, and heights does not include Batteries, Battery Charger, or Switchgear.

Table 4. Size, Weight, and Cost of System C

COMPONENT	UNIT KW	OUTPUT	SPEED (RPM)	L (in)	W (in)	H (in)	WT (lb)	COST
	100 KW							
Alternator		100 KW	3600	44	21	21	1,290	$ 3,600
AC Motor		150 HP	3600	36	22	23	1,210	3,410
Gas Turbine		315 HP	3600	60	40	34	675	18,000
Flywheel		- -	3600	- -	4	48	1,675	1,300
Switchgear, Profit, etc.		- -	- -	27	35	74	2,500	30,000
TOTAL *				12 ft	4 ft	4 ft	7,350	$ 56,310

* Total length, width, and height does not include switchgear.

to the controls and minor components of comparable diesel units upon which their size, cost, and weight estimates were based.[1] System C estimates are an indication of what can be accomplished if a gas turbine can be turned at full speed by an outside source of power. This system cannot be constructed at the present time since gas turbines now being manufactured cannot be operated in this manner. The Diesel System listed can provide the same frequency and voltage control as Systems A, B, and C; therefore, these three systems can be compared on an equivalent basis. Cost estimates for System D were not made, since this system was not considered to be practical based on the findings of Section D.

F. Comparison of Operating and Maintenance Costs

A cost comparison of the operating and maintenance costs of the various systems considered is shown in Table 5. Operation is based on 8560 hours of annual operation from normal Utility power and 200 hours annual operation from standby power. Diesel fuel costs were computed at $0.10 per gallon and electric energy at $0.009 per KWH . Electric energy for the diesel systems is based on test data supplied by TMC Power Distribution Inc.

Maintenance costs contained in Table 6 are based on a study made by the Bureau of Yards and Docks[3] for the maintenance of various diesel units and on maintenance data received from AiResearch for gas turbines. The gas turbine overhaul costs were estimated on an overhaul frequency of 1,000 hours. It should be noted that in the near future this may be extended to as much as 10,000 hours. A large part of the maintenance costs are for "checking and inspection" which probably can

be reduced as knowledge on reliability and maintenance practices can be established. While Systems A and B differ slightly, it is considered that the difference in their maintenance cost would be so small that they could be listed together.

Table 5. Comparison of Operating and Maintenance Costs

SYSTEM	40 KW	60 KW	100 KW	150 KW	200 KW
Diesel (60°)					
Fuel Oil	$ 104	$ 152	$ 132	$ 196	$ 262
Electricity	3,850	5,780	9,640	14,400	19,300
TOTAL	$3,954	$5,932	$9,772	$14,596	$19,562
System A (60°)					
Fuel Oil	$ 280	$ 390	$ 680	$ 800	$ 940
Electricity	3,850	5,780	9,640	14,400	19,300
TOTAL	$4,130	$6,170	$10,320	$15,200	$20,240
System B (60°)					
Fuel Oil	$ 280	$ 390	$ 600	$ 800	$ 940
Electricity	3,780	5,620	9,300	14,020	18,600
TOTAL	$4,060	$6,010	$9,980	$14,820	$19,540
System C (60°)					
Fuel Oil	- - -	- - -	$ 680	- - -	- - -
Electricity	- - -	- - -	9,300	- - -	- - -
TOTAL			$9,930		

Table 6. Comparison of Maintenance Costs

SYSTEM	40 KW	60 KW	100 KW	150 KW	200 KW
Diesel	$1,200	$1,600	$2,000	$2,600	$3,000
Systems A & B	$1,950	$2,000	$2,000	$2,370	$2,470
System C	- - -	- - -	$1,670	- - -	- - -

Since the different systems are actually very similar it is considered that their expected life would be about the same and that with proper maintenance could be expected to last for 15 to 20 years. Replacement costs, interest, etc., was not considered in the above operating costs.

G. Installation Costs

For the purpose of installation costs, shown in Table 7, the following conditions were assumed:

1. Net floor space required for the equipment was doubled and this space, at \$18 per sq ft was used to compute the building cost. This cost includes heating (60°F minimum inside design temperature), lighting, and duct work for exhaust and intake air. The slight additional costs of the diesel foundation would approximately be offset by a battery vent on systems A and B.

2. Operating noise (especially with the gas turbine) may be a problem; however, if masonary or concrete structures are used to contain the equipment and if this building can be somewhat isolated from the main building, the noise effect can be reduced. If noise is a problem, commercially available equipment, which includes intake and exhaust baffle and acoustic panel silencers, soundproof panel enclosures and doors, as manufactured by Industrial Acoustics Co. Inc., could be used.

3. Yearly maintenance costs for the buildings over the life of the equipment, due to the type of construction and small size is considered to be negligible.

4. Due to the limited operation of the diesel and gas turbine no special fuel arrangements are necessary except mounting a fuel tank

outside the building for the larger engines. Fuel storage capacity ranges from 60 to 500 gallons for 10 hours operation, which is considered to be the maximum emergency operations period. These costs were included in the basic costs of the various systems.

5. Since each installation will be different, no costs are included for any wiring outside the no-break system. A detailed survey should be made in each case to determine the exact cost of isolating the critical load and connecting it to the no-break system.

Table 7. Comparison of Installation Costs

SYSTEM	40 KW	60 KW	100 KW	150 KW	200 KW
Diesel	$3,200	$3,780	$4,200	$4,420	$5,290
System A	$2,300	$2,410	$3,200	$3,750	$4,000
System B	$2,630	$2,740	$3,780	$4,320	$4,750
System C	- - -	- - -	$2,050	- - -	- - -

H. Summary of System Cost, Size, and Weight

Table 8 is a tabulation of the yearly cost of owning and operating the various systems for a 20 year period as compared to the cost of electricity alone without any type of no-break system. These costs are shown graphically in Figure IX. It can be seen that the cost for all four systems is rather close; however, the Diesel System has the lowest cost with the exception of System C which cannot be produced at the present time. As shown in Figure X and XI all of the gas turbine systems weigh less and require less floor space than the diesel systems.

As indicated in these three graphs, the gas turbine no-break power system is not only possible, but is very close to being competitive with diesel units. With further refinements in gas turbines it is possible that these systems will have greater advantages than the diesel systems.

Table 8. Yearly Owning and Operating Costs

SYSTEM	40 KW	60 KW	100 KW	150 KW	200 KW
Diesel System					
Basic System	$1,810	$ 2,180	$ 3,120	$ 3,380	$ 4,050
Fuel & Elect.	3,950	5,930	9,770	14,600	19,560
Maintenance	1,200	1,600	2,000	2,600	3,000
Installation	160	190	210	220	270
TOTAL	$7,120	$ 9,900	$15,100	$20,800	$26,880
System A					
Basic System	$2,940	$ 3,400	$ 4,500	$ 5,220	$ 5,760
Fuel & Elect.	4,130	6,170	10,320	15,200	20,240
Maintenance	1,950	2,000	2,000	2,370	2,470
Installation	115	120	160	180	200
TOTAL	$9,135	$11,690	$16,980	$22,970	$28,670
System B					
Basic System	$2,850	$ 3,230	$ 4,240	$ 4,820	$ 5,280
Fuel & Elect.	4,060	6,010	9,980	14,820	19,540
Maintenance	1,950	2,000	2,000	2,370	2,470
Installation	130	135	190	215	240
TOTAL	$8,990	$11,375	$16,410	$22,225	$27,530
System C					
Basic System	- - -	- - -	$ 2,820	- - -	- - -
Fuel & Elect.	- - -	- - -	9,930	- - -	- - -
Maintenance	- - -	- - -	1,670	- - -	- - -
Installation	- - -	- - -	100	- - -	- - -
TOTAL			$14,520		
Cost of Electrical Energy Without Any No-break System	$3,150	$4,720	$7,900	$11,800	$15,750

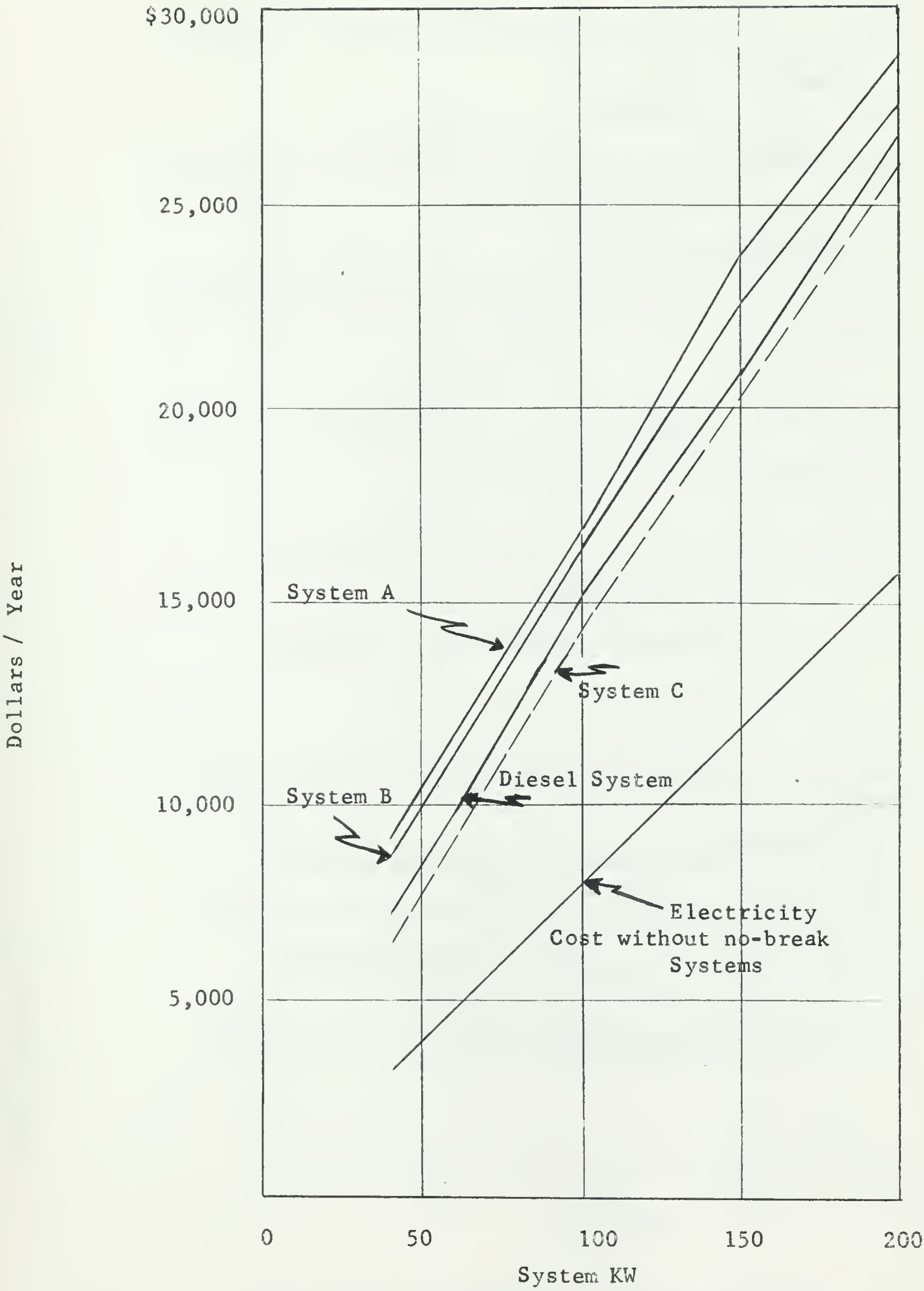

Figure IX. Yearly Owning & Operating Costs

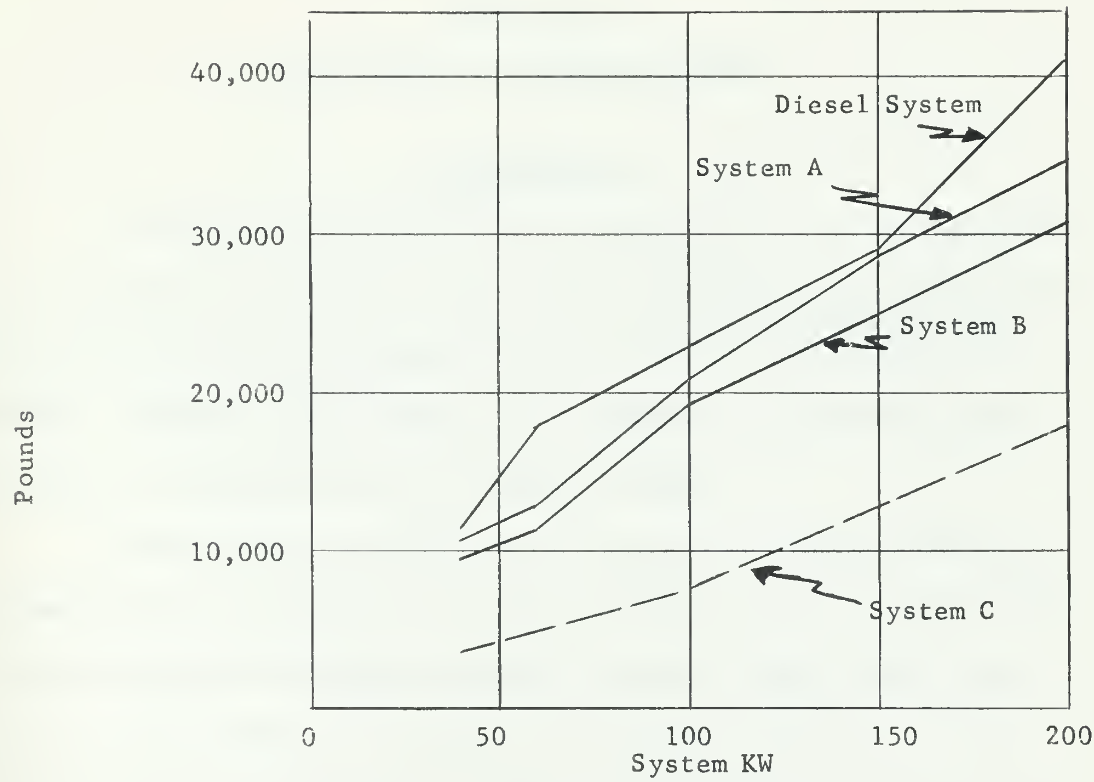

Figure X. System Weight Comparison

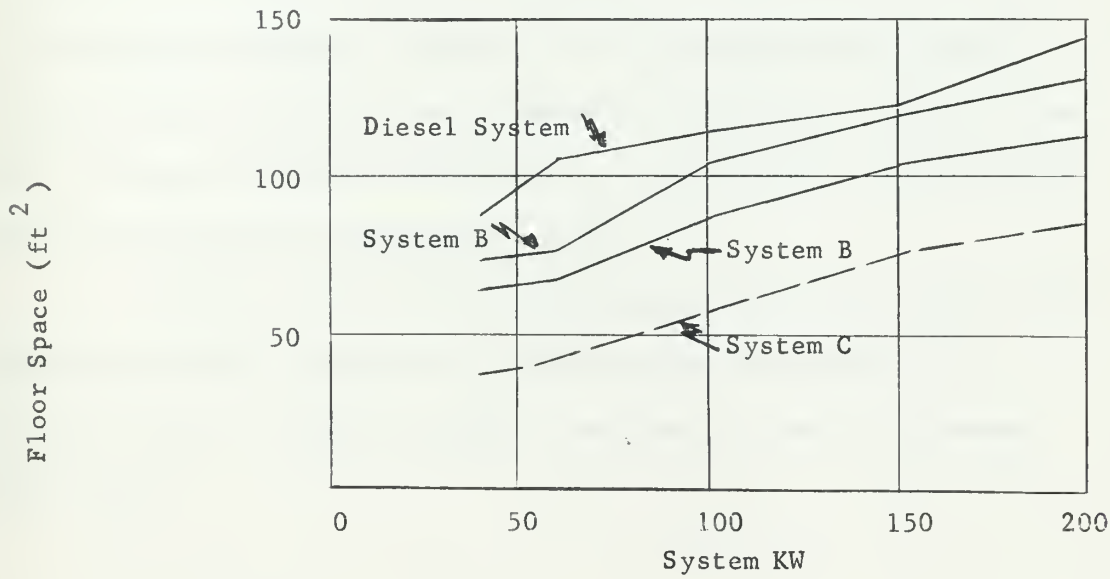

Figure XI. System Floor Space Comparison

PART III

CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

It can be concluded from this study that it is not possible at the present time to build a gas turbine no-break power system that will satisfy all the requirements set forth in the STATEMENT OF THE PROBLEM. Systems A and B accomplish a reduction in size and weight but only at additional cost over diesel systems.

System B is considered to be superior to System A since it is less costly and because the Utility voltage can vary 5 to 10% (the AC motor speed will be fairly constant over this range) before the critical load voltage and frequency are affected, compared to a 2% voltage variation on System B. System B does have the advantage that frequency variations have little or no effect on the critical load frequency, while the critical load frequency of System A is the same as the Utility frequency. However, it is considered that voltage variations will normally be more numerous than frequency variation and also if numerous frequency variations are encountered, they will probably be accompanied by voltage variations.

System C, if it can be manufactured, will satisfy all of the design requirements, since it is rugged, meets the criteria, is smaller, lighter in weight, simpler, and lower in cost than present diesel units.

B. Recommendations

It is recommended that:

1. Gas turbine manufacturers be encouraged to develope a gas turbine as described in System C.

2. Evaluation of gas turbines be continued, since improvements and cost reductions will affect the economics of Systems A and B, making them more desirable.

PART IV

LITERATURE CITED

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Bureau of Yards and Docks, Navy Department. p. 13-14, 16-17.

2. "Power Generation, Distribution and Air Conditioning Study for Augmented Four-Wheels System." AiResearch Manufacturing Company of Arizona. p. 12-16, 19-21.

3. "1963 Gas Turbine Specifications" GAS TURBINE, v. 4 , no. 1
p. 51-516, January-February, 1963.

PART V

APPENDIX A

Gas Turbine Manufacturers and Data [3]

MANUFACTURER	MODEL	H.P.	TURBINE RPM	WT (lb)	L (in)	W (in)	H (in)
AiResearch Manufacturing Phoenix, Arizona	GPT30	60	52,800	68	21	18	17
	GTP70	160	40,800	224	32	31	25
	GTCP85	345	40,800	284	43	26	22
	GTP831	400	39,000	658	59	38	30
	GTP807	315	40,800	284	43	26	22
Allison Division of General Motors Corp., Indianapolis, Ind.	GMT-305	175	25,000	765	41	32	28
The Boeing Company, Seattle, Washington	502-10MA	300	30,300	335	42	24	24
	502-22	200	26,000	400	42	24	24
Chrysler Corp., Detroit, Michigan	CR2A	140	45,730	450	36	35	27
The Cooper-Bessemer Corporation Mount Vernon, Ohio	RT-110	350	33,000	225	58	19	36
Energy Transformation Corporation Boyertown, Penn.	2GGT	65	39,000	110	24	16	15
	1GGT	80	42,000	75	21	15	15
Solar San Diego, Calif.	T-41 M	60	40,000	100	28	17	24
	T-350	350	35,100	195	37	28	27
	T-62 T	65	56,700	66	26	18	17
Vector Corporation, Troy, Michigan	- - -	100	48,500	100	40	14	14